PA Discussion Topics

Tank Automotive Research, Development & Engineering Center

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Ground Vehicle Power & Mobility

Report Documentation Page

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PA Discussion Topics

Organization	Title	TARDEC Position
ADD-TARDEC	High Performance Power Electronics Based on SiC(Silicon Carbide)	TARDEC has a program – Continue discussion
ADD-TARDEC	Thermal Management System for Hybrid Electric Vehicles	TARDEC has a program – Continue discussion
ADD-TARDEC	Electro-Mechanical Transmission	TARDEC has interest, skills and personnel, but no program – lower priority discussion
ADD-TARDEC	Network Centric Military Energy Control (NCMEC)	Future discussion
ADD-TARDEC	M&S for Hybrid Electric Vehicles	Future discussion
TARDEC-ADD	Battery Research	TARDEC has a program – Continue discussion
TARDEC-ADD	Fuel Cell Based Auxiliary Power	TARDEC has a program – Continue discussion
TARDEC-ADD	Fuel Cell Based Robot Power	TARDEC has a program – Continue discussion

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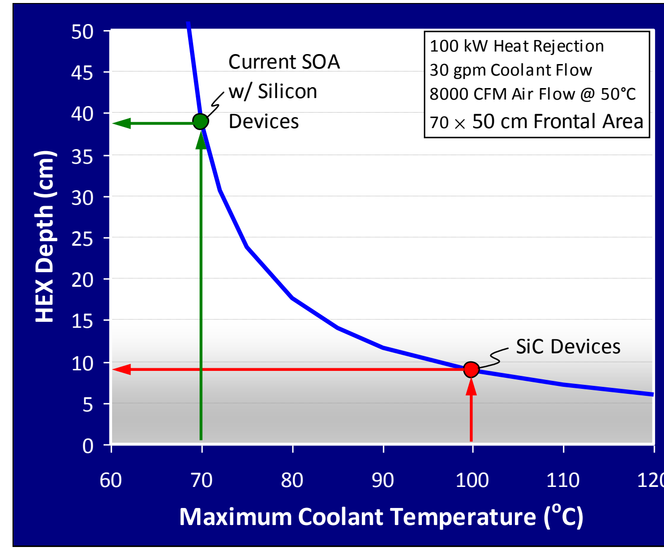
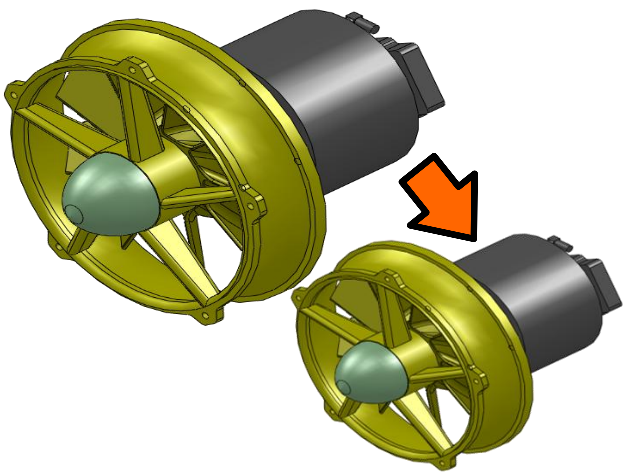
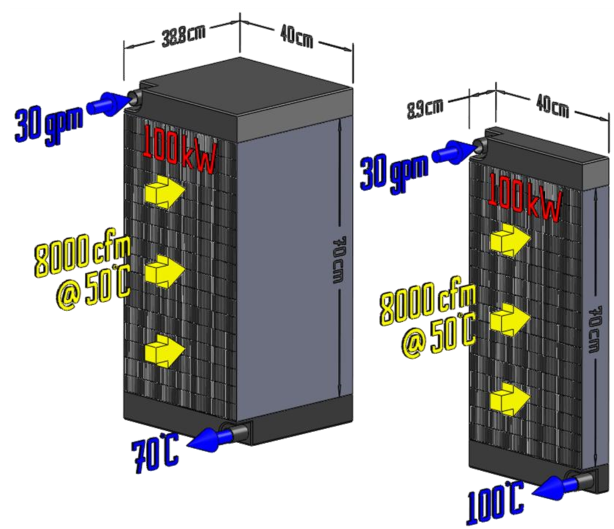
Improved Power Electronics Attributes

Si based power electronics require coolant inlet Temperature not to exceed 70°C resulting in large cooling system size

SiC can operate at much higher temperatures (≥ 100°C thus reducing the size of the cooling system by half







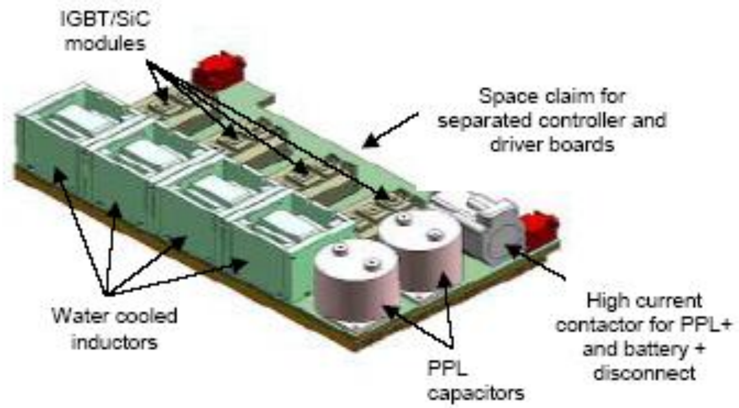
Advanced SiC Components will Reduce the Power Electronics Cooling Burden

Power Electronics

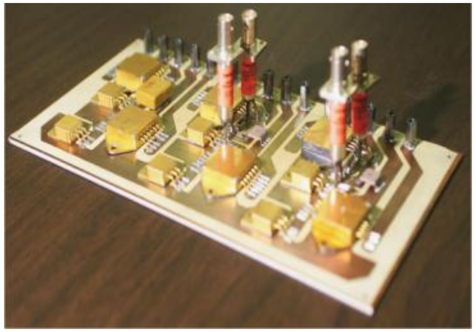
Thrust is SiC to overcome:

- Thermal issues
- Efficiency
- Low frequency requiring large capacitors
- Low power density

Approach: Develop power devices using SiC diodes as an interim step
Develop All SiC motor drives and DC-DC converters as the device technology matures



100 kW Si/Si-C hybrid DC-DC converter



All-Si-C motor-drive inverter

SiC PiN Diode Module

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Hybrid SiC/Silicon DC-DC Converter

Controller Board

PPL Bus Bars

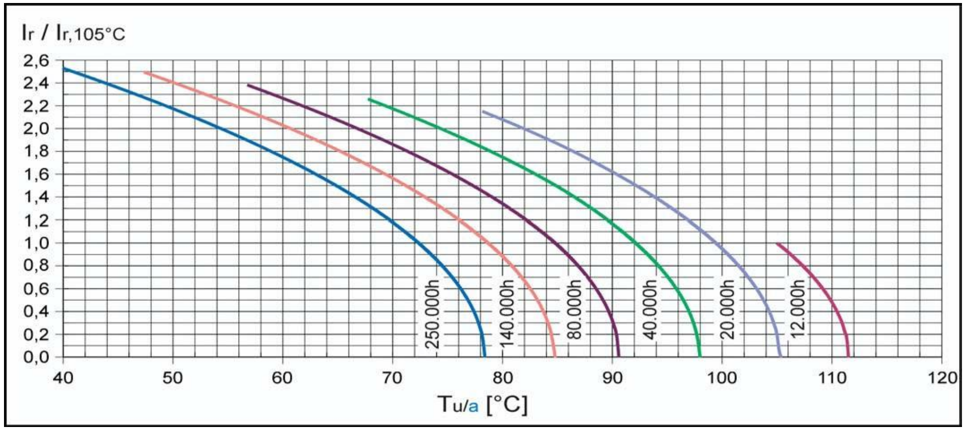
Battery Bus Bars

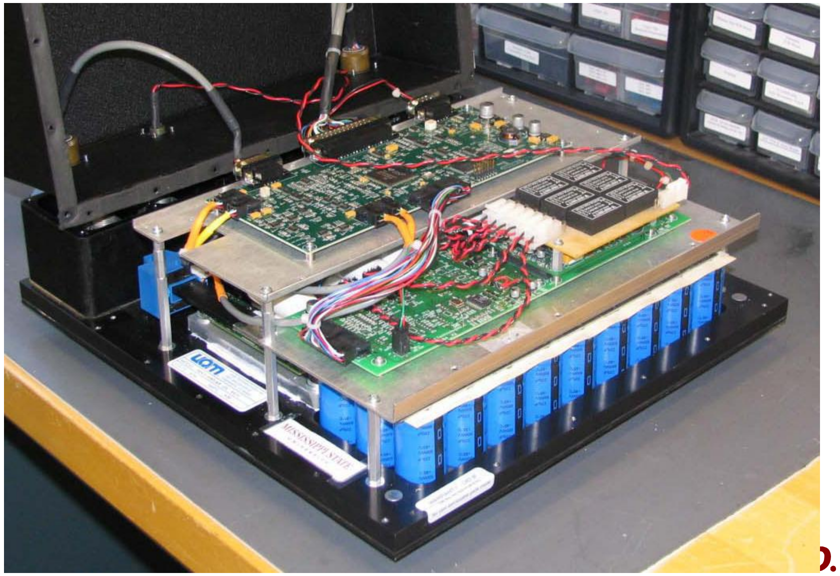
Power, Signal and Cooling Connection Area

Other High Temperature Components

- **Military export power applications require high capacitance when available energy storage is minimal or absent**
  - High temperature electrolytic power capacitors – progress in this area shown to the right
  - Address capacitance per unit volume for power density
- **Other required high temperature devices**
  - Integrated circuit chips
  - Current sensors
  - Signal capacitors

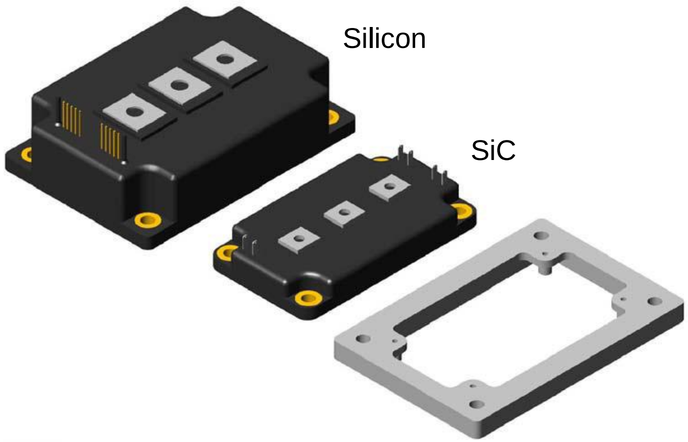
Capacitor Life/Temp Curves



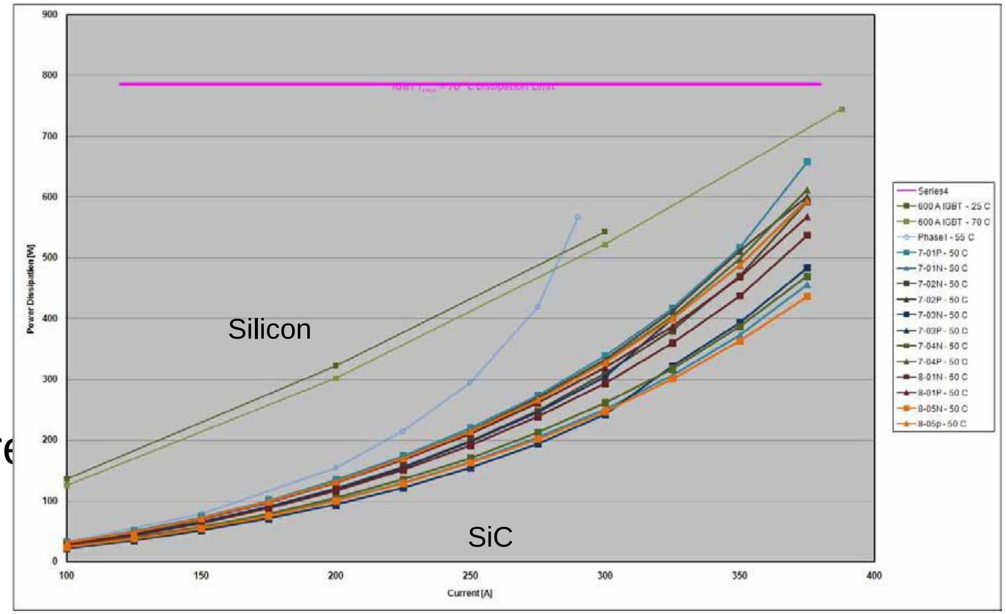


Silicon Carbide Efficiency

- **Technology successfully demonstrated by UQM/MSU team:**
  - 30 kW of power from SiC JFETs
  - Reduced losses compared to silicon IGBT technology



- **Next Generation devices now available**
  - 1200 V enhancement-mode JFETs ("normally off")
  - Larger die size (<0.1 Ω)
    Leading to manufacturing improvement
  - Maximum junction tempera- ture of 200 degrees C



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Silicon Carbide Development Issues

- **Material Quality and Size**:
  - SiC material has high concentrations of dislocation defects
  - Micropipe density is still routinely 2-5/cm^2 which limits current carrying capacity to about 20 Amps
    (material with fewer defects is available at higher cost)
  - Material improvement is essential to improve yield and reduce costs
  - Significant cost reduction possible if size can be increased to 150 mm. diameter

- **Device Development**
  - MOSFETS: Historically have reliability issues at high temperatures.
    Cost and yield are still issues
  - JFETs: no known critical reliability issues
  - BJTs: unreliable due to basal plane defects, but material has been improved
  - Thyristors: may be useful for very high power applications (utilities and pulsed power)

- **Current Ratings**
  - 20A SiC MOSFETS are commercially available
  - 20A – 50A SiC diodes are commercially available
  - 15A Normall-off JFETs are available now (higher current devices are not yet available)

Ultimately 50-200A individual switches and 300A-1400A switch modules are required

Silicon Carbide Power Converter Development

- **OBJECTIVES:**

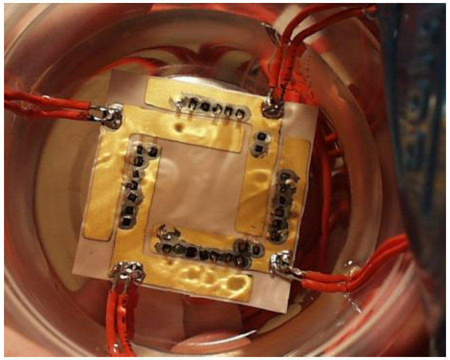
    Reduce Thermal Burden on Vehicles
    Reduce Converter Operating Power

- **APPROACH:**

Develop compact, efficient, lightweight, high-temperature power converters using advanced SiC semiconductor power modules at power ratings needed for high-power military applications

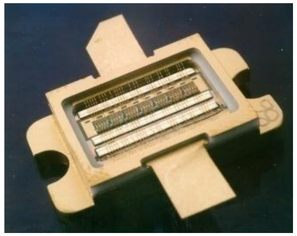
- **TARGET APPLICATIONS:**
    - 200 kW Traction Motor Drive Inverter
    - 50 kW Motor Drive Inverter for pumps, fans
    - 30 kW Bi-directional DC-DC converter (300Vdc to 28Vdc
    - 180 kW Bi-directional DC-DC converter (300V Battery-to-600V Bus)
    - 30 kW AC Export Power Inverter 300Vdc-to -60Hz
      @ 110Vac, 220Vac & 208Vac (3-phase)

Silicon Carbide Devices



2.7kV, 25kW
SiC Rectifier

SiC JFET



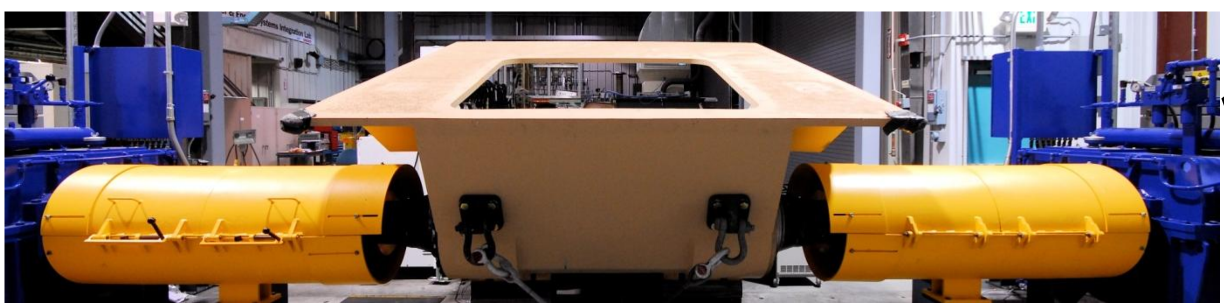
MOSFET

Power and Energy System Integration Lab (SIL)

The SIL provides capability to accelerate the integration and maturation of critical hybrid system technologies in order to meet advanced vehicle performance within weight and volume constraints

System Integration

System integration into vehicle platform



HOTBUCK platform with FCS hardware

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Energy Storage Overview

- **Energy Storage Goals & Mission**
- **DOD Power & Energy Requirements**
- **DOD Energy Storage R&D Challenges**
- **Vehicle Applications & Approach**
- **Army Ground Vehicle Energy Storage R&D Programs**
  - Roadmap
  - Functional Breakdown/ Highlighted R&D Programs & Projects
- **Summary**

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Energy Storage Goals and Mission

Energy Storage Goals

- Develop **safe, reliable and cost** effective energy storage systems
- Reduce **battery weight & volume burden** (Increase Energy & Power Density)
- Reduce logistics and fuel burdens
- Enhance performance, extend **calendar and cycle life**

Energy Storage Mission

- **Develop** and **mature** advanced ES technologies for transfer to vehicle platforms
- Test & evaluate ES technologies for prequalification and to **assess TRL (Technology Readiness Level).**
- Identify **technology barriers** and develop technical solutions
- Be recognized as the team of experts in ES components and systems
- Provide technical support to customers, other teams and government agencies for all ES requirements
- Provide **cradle-to-grave** support for all Army ES systems

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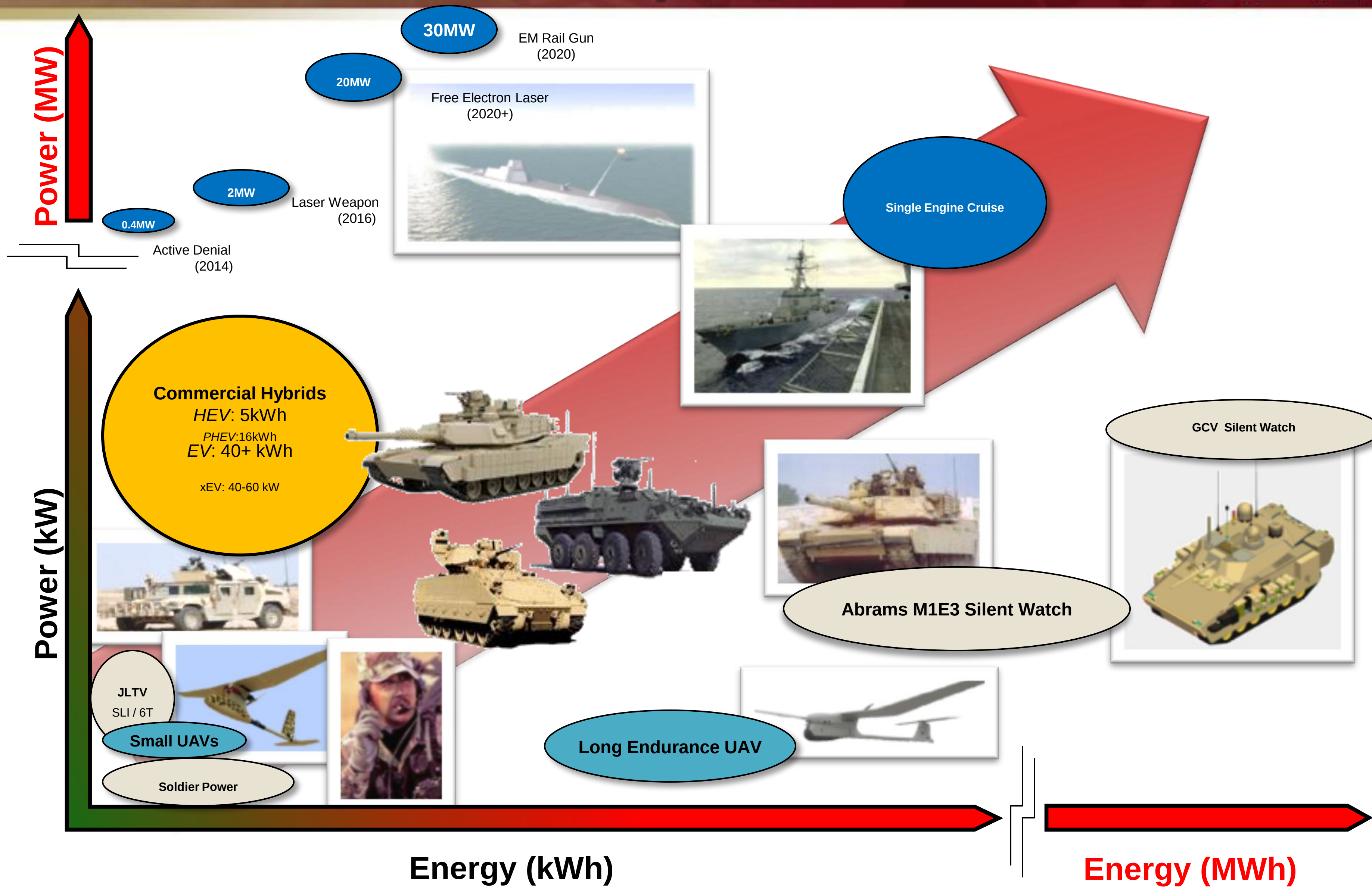
DOD Power & Energy Requirements



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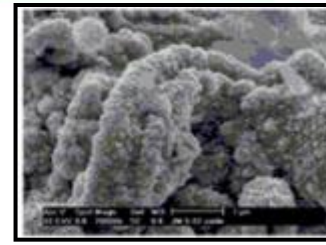
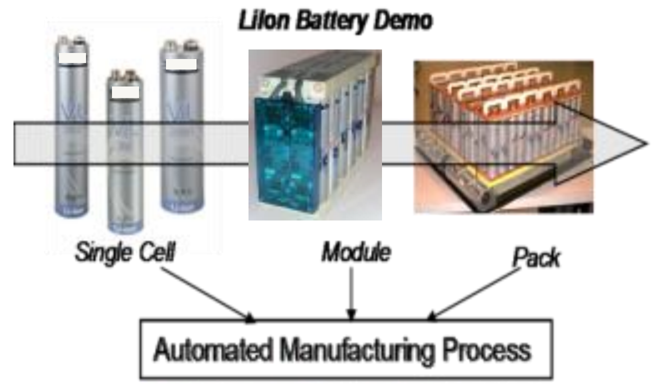
Energy Storage Technology Challenges

Energy Storage Challenges:

- Cell & system safety & reliability
- Higher energy / higher power designs & chemistries
- Power vs. energy trade-off design optimization
- Manufacturing process development and cost control
- Thermal management
- System control and cell & battery management systems
- Alternative electrochemical improvements
- Thermal runaway process and its control
- Standardization of cells, modules and packs (logistics)





Army Applications & Approach

- **Army Applications/Drivers:**

TARDEC - Ground

– Major Applications

- Robotics
- Survivability
- Weapons Systems
- Electromagnetic Armor (EM Armor)
- Starting, Lighting and Ignition (SLI)
- Hybrid Vehicle Acceleration and Silent Mobility
- Silent Watch

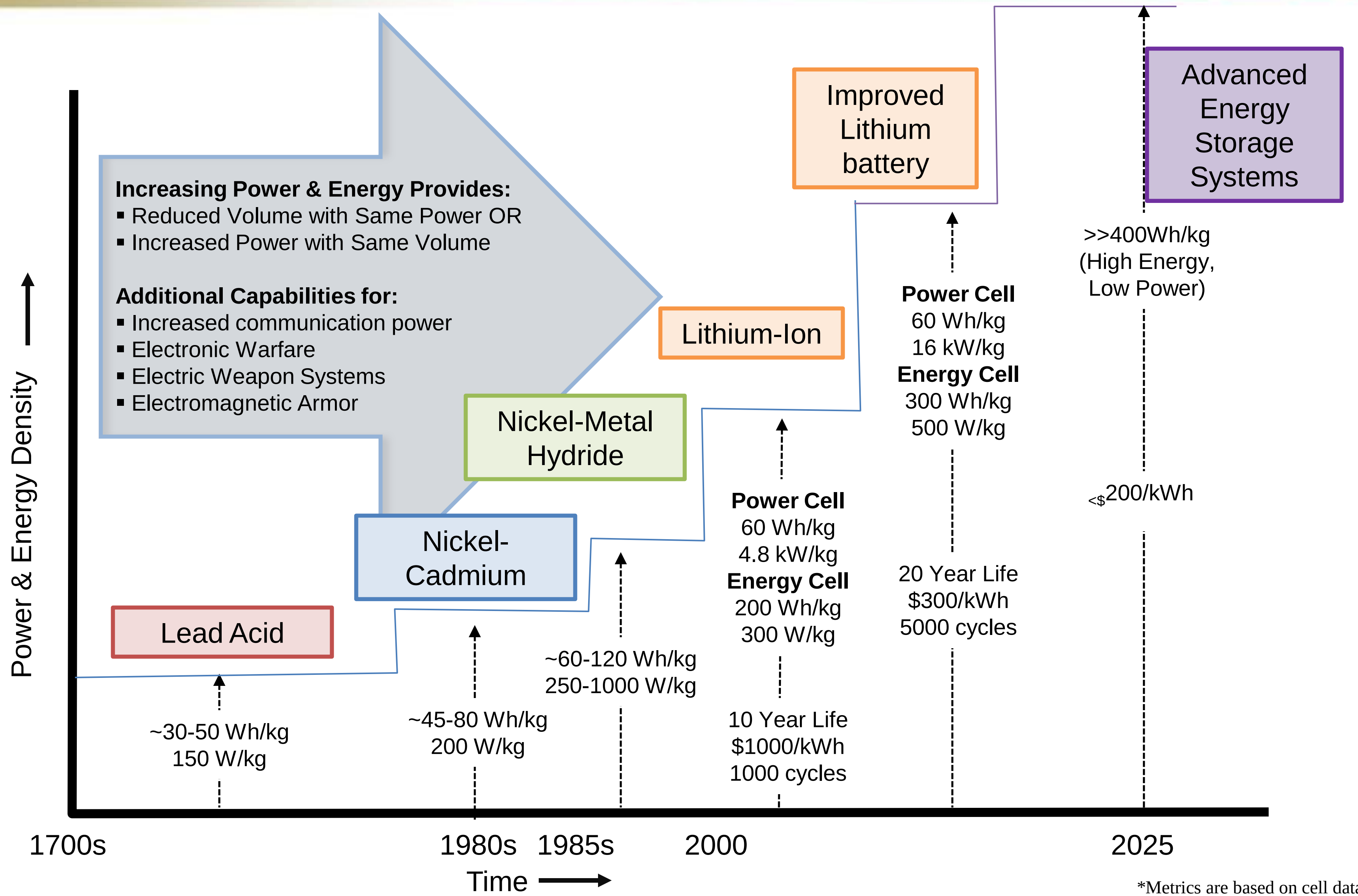
Hit Avoidance

Targeting Systems

– Approach
- Standard Form Factor (6T)
- Ultra-capacitor/Battery/Fuel Cell Hybrid Power Sources

– **Energy Storage Team Focuses on Batteries:**
- True silent watch and silent mobility
- Serves as reservoir to store energy to meet power demands and manage platform power
- Provide power source for advanced weapons.

Battery Roadmap: Battery Power and Energy Versus Time



*Metrics are based on cell data

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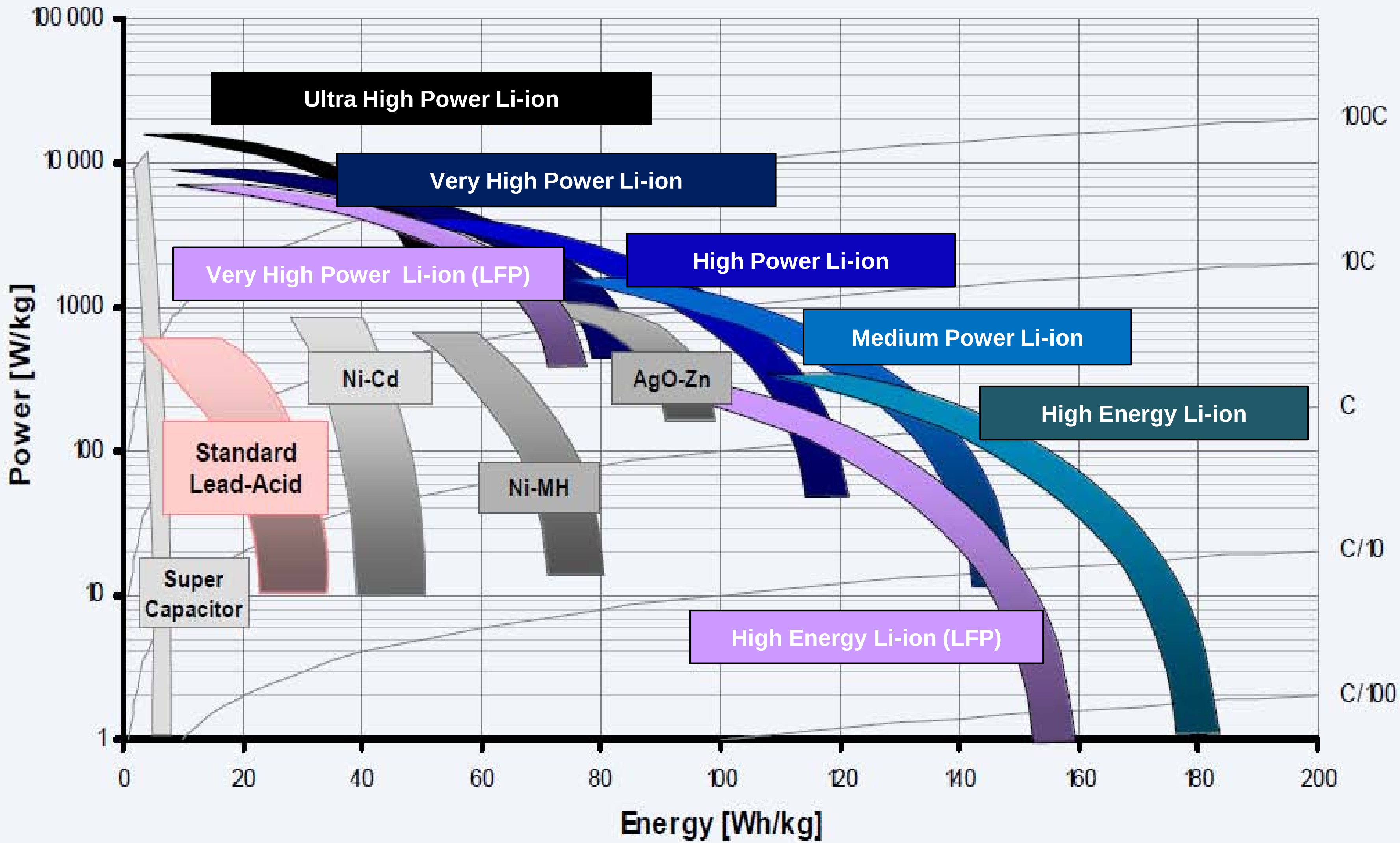
Energy Storage Technology Trade-Offs & Capabilities



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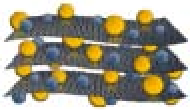
Energy Storage Functional Breakdown



Basic Research

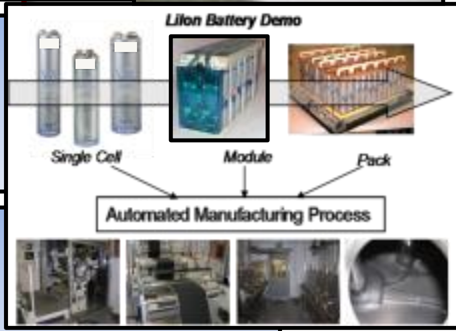
- Lithium plating phenomenon in Li-ion batteries
- **Study on the mechanism of thermal runaway in VRLA Batteries and Methods of Suppression**
- Study of electrode/current collector interface & safe separator for Li-ion batteries
- Development of high energy density anode materials for improved Li-ion batteries
- Alternative electrolyte for use in lithium-ion batteries (higher voltage, improved performance)

Applied / Applications Research

- Electromagnetic Armor Power Maturation
- Nickel-Zinc 6T Battery Development
- **Development of 6T battery for SLI and silent watch using Li-ion chemistries**
- Absorbed Glass Matt lead acid battery for 24V military 4HN battery

Manufacturing

- High Power, High Energy Density Li-Ion Battery Manufacturing Program
- **Lithium-Ion Cell/Battery Pack Manufacturing**
- Advanced battery material scale-up facility

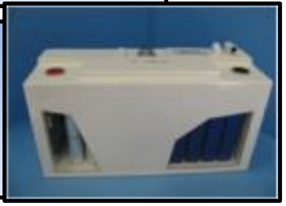


Battery Management / Safety

- **In-House BMS evaluation for PM HBCT & new laboratory**
- Universal BMS using novel algorithms for battery health
- Ballistic and abuse tolerance studies on cells, module and packs
- Development of advanced diagnostic tools for cycled cells

Alternative Systems

- Hybrid Power Module
- Lithium-Titanate Hybrid Vehicle Pack Integration
- **Characterization of ultra-capacitors for SLI and high power applications**



Energy Storage Summary

- **Army has a diversified energy storage portfolio supporting a wide-range of customers**
- **Army has and is actively seeking collaboration with other Government Agencies, and Commercial & Military OEM's**
- **Army has projects supporting several different functional areas in Energy Storage including: basic research, applied research & applications, manufacturing, battery management & safety, and alternative systems**
- **Army labs currently perform a wide variety of testing activities and has an established program for technology maturation and technology readiness level verification**
- **Army is actively involved in the development of battery standards and standard vehicle battery products**

Non-primary Power Systems (NPS) Technology Focus Areas

Small Engines

- Achieve increased power density for existing vehicle APU space claims
- Optimize injectors for heavy fuels
- Minimize acoustic signature

Reformation/Fuel Cells

- Achieve increased power density for existing vehicle APU space claims
- Optimize system integration and controls

Robotic Power

- Achieve increased range (vs. current batteries) with small engine and fuel cell-based power sources
- Minimize acoustic signature of small engine-based robotic platforms
- Increase fuel cell reliability and shock and vibration performance

Mission Goals for each Focus Area:

- High Power Density Engine APU that can provide up to 45 kWe auxiliary power to meet increasing onboard vehicle power demands without reducing mobility.
- Silent Watch (undetectable at 50m) through the use of a fuel cell based APU that powers mission equipment with main engine off while the vehicle is stationary, with reduced acoustic and thermal signature.
- Small UGV power through small engine and fuel cell based solutions that can extend the mission duration and range of UGVs, reducing risks to soldiers.

Non-Primary Power Systems
Technical Challenges

- Obtain 45kW in current or smaller space claim
- 2.5 gallon/hr for 25kW output
- Undetectable at 50 meters
- Mean time between failure 1140 hours

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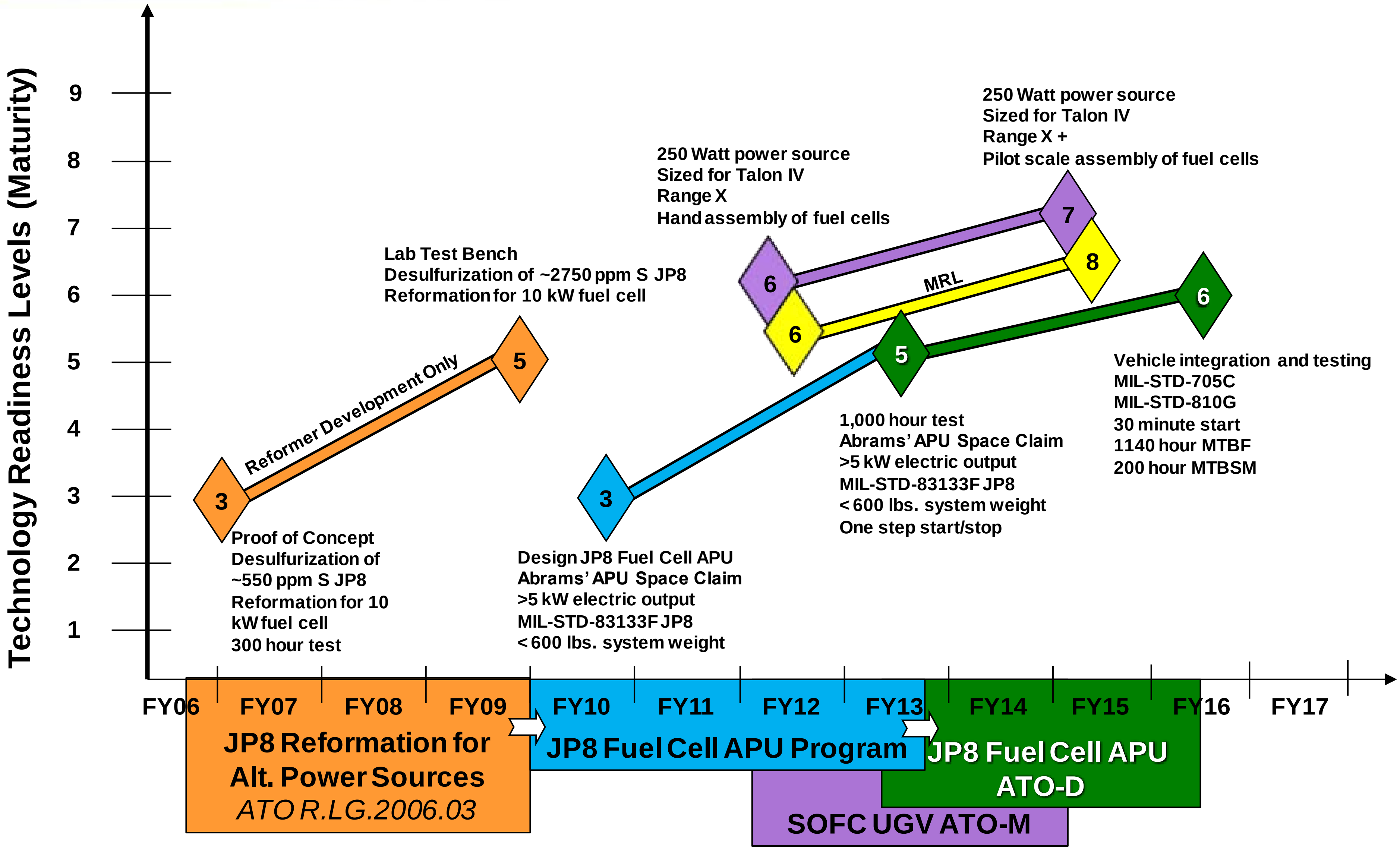
TARDEC Fuel Cell Roadmap



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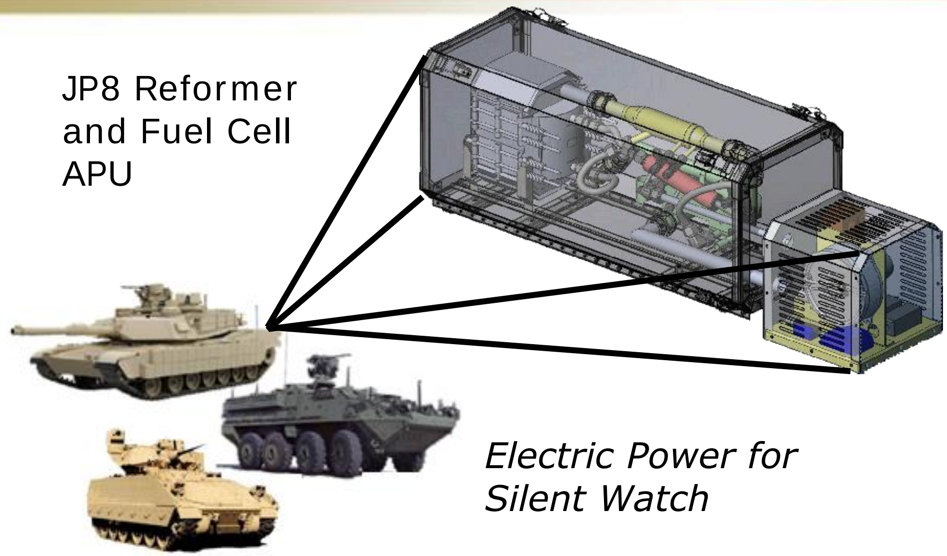
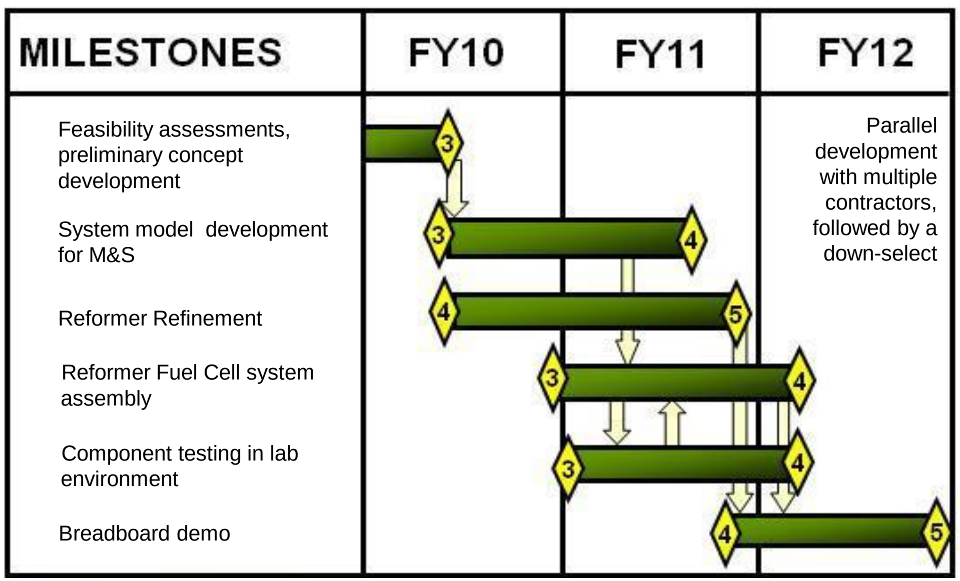
JP-8 Fuel Cell APU System

JP8 Reformer and Fuel Cell APU



Electric Power for Silent Watch



Purpose:

Provide quiet, continuous, non-primary electrical power for extended engine-off operation with reduced acoustic and thermal signatures in a ground-breaking fuel cell based APU.

Products:

- JP8 Reforming fuel cell-based Auxiliary Power Unit (APU) that delivers 5 kWe (Threshold), 10 kWe (Objective) of vehicle electrical power demonstrated at TRL 5.
- System designed to fit into an existing military ground vehicle APU space claim of approximately 225 liters.
- Line Replaceable Unit (LRU) for plug and play integration for legacy fleet vehicles.

Payoff:

- Provide low signature, non-primary vehicle power generation for C4ISR and auxiliary systems (engine off).
- Increase the warfighter’s survivability and lethality through decreased signature during extended silent watch missions.
- Increase overall vehicle fuel efficiency to reduce fuel logistics burden.
- Provide power for soldier equipment during transport and watch mission scenarios.

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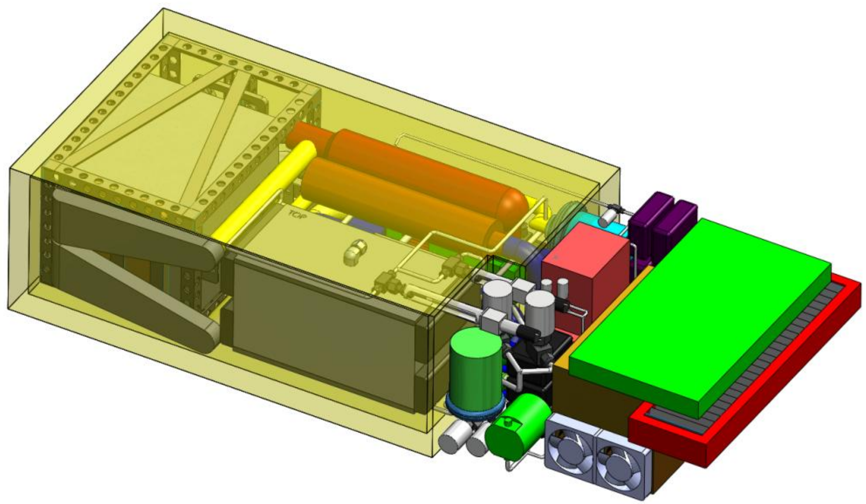
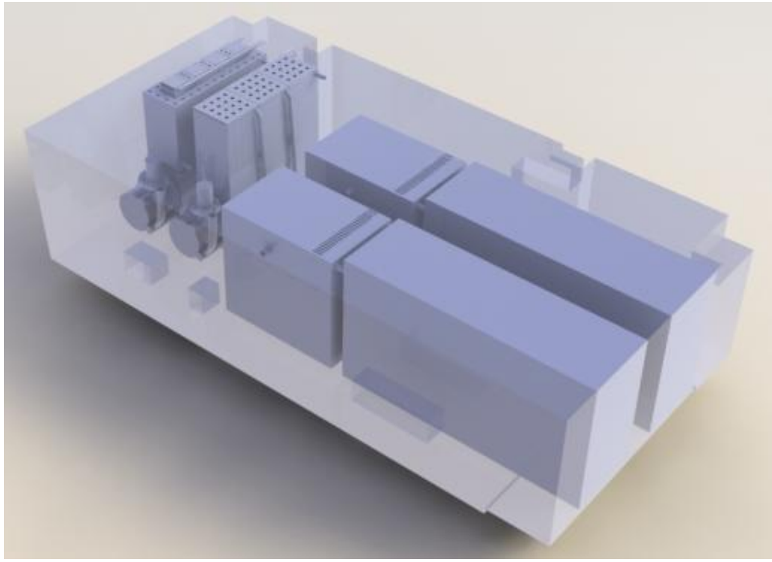
Parallel Approach

Solid Oxide Fuel Cell Approach



JP-8 Fuel → Liquid Phase Desulfurization → Autothermal Reformation → Solid Oxide Fuel Cell → 7 kWe at 28 V DC

High Temperature PEM Approach



JP-8 Fuel → Fractionation → Gas Phase Desulfurization → Steam Reformation → Water Gas Shift → High Temperature PEM Fuel Cell → 10 kWe at 28 V DC

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Unmanned Robotic System Utilizing Hydrocarbon Fueled Oxide Fuel Cell

Current Program

Project Purpose/Goals

- To integrate a 250 Watt Solid Oxide Fuel Cell system onto an existing Unmanned Ground Vehicle (UGV)
- Analyze current manufacturing process and perform a low rate initial production of 20 units
- Analyze production cost and unit variability
- Test 5 units at contractor facility for 2000 hours or failure
- To test the system with expected shock and vibration loads typically seen on a UGV
- Perform a user/safety assessment with experienced users

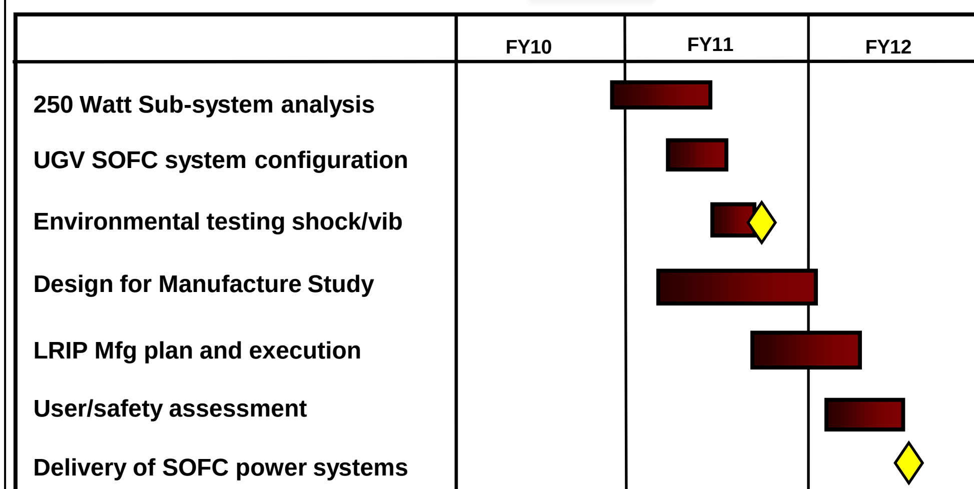
Technology Description:

- 250 Watt Solid Oxide Fuel Cell System
- Uses commercially available propane
- Fits into existing battery compartment
- Power system can be used as stand alone power source
- Increases mission duration over batteries

Challenges:

- Limited shock and vibration testing
- Meeting limited space constraints
- Manufacturability

Schedule



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RDECOM

Extended Mission Capability for UGVs using Hybrid Fuel Cells

TARDEC

iROBOT PACKBOT FUEL CELL

developed under previous effort with AMI

- Hybrid fuel cell system is designed to replace the existing batteries on a packbot with a Solid Oxide fuel cell and Lithium Ion battery (~150 watts)
- Enables extended mission durations
- 12 hours of full power; 30 hours of silent watch.
- Operates on commercially available propane as fuel Plug-and-play design, easily replaces batteries
- Hybrid setup removes any need for removal of batteries for charging; only requires propane fuel canister replacement.
- Startup in under 20 miuntes
- Significantly increases mission duration while adding minimal weight. (5.7 kg with batteries)
- Fills 2 payload spaces

SCHEDULE

	FY11	FY12
Manufacturing Prototype SOFC System Design		
•Concept Analysis and Design Review		
•Design Battery Maintaining System		
•Design air handling, fuel handling, fuel cell core, and user interface		
•Design multi-purpose housing		
•Test complete system		
SOFC Manufacturability		
•Perform a 'Design for Manufacturability' study		
•Perform industrial base assessment		
•Design and implement a manufacturing plan for LRIP		
•Operate/Test 5 units for 2000 hours		
•Safety / User Assessment in relevant environment		
•Deliver units		

QINETIQ TALON

Current effort

- Hybrid fuel cell system is designed to replace the existing lead-acid batteries with an upgraded Solid Oxide fuel cell and Lithium Ion battery (~250 watts)
- Development to include system upgrade to 250 watts, optimization of battery maintaining system and design system to fit TALON battery space claim
- Manufacturability study to be conducted to optimize system components to lower costs and decrease part variabilities.
- 20 units to be built; 5 units will be tested at AMI for 2000 hours or until failure (with a study on the failure, if any), and 15 units to be sent for users to test in a relevant environment.
- All 20 units to be delivered to TARDEC at the end of the effort.

It's all about…Supporting the Warfighter